

Minimum Δv Burn Planning for the International Space Station Using a Hybrid Optimization Technique, Level 1

Aaron J. Brown

Abstract

The International Space Station's (ISS) trajectory is coordinated and executed by the Trajectory Operations and Planning (TOPO) group at NASA's Johnson Space Center. TOPO group personnel routinely generate look-ahead trajectories for the ISS that incorporate translation burns needed to maintain its orbit over the next three to twelve months. The burns are modeled as in-plane, horizontal burns, and must meet operational trajectory constraints imposed by both NASA and the Russian Space Agency. In generating these trajectories, TOPO personnel must determine the number of burns to model, each burn's Time of Ignition (TIG), and magnitude (i.e. Δv) that meet these constraints. The current process for targeting these burns is manually intensive, and does not take advantage of more modern techniques that can reduce the workload needed to find feasible burn solutions, i.e. solutions that simply meet the constraints, or provide optimal burn solutions that minimize the total Δv while simultaneously meeting the constraints.

A two-level, hybrid optimization technique is proposed to find both feasible and globally optimal burn solutions for ISS trajectory planning. For optimal solutions, the technique breaks the optimization problem into two distinct sub-problems, one for choosing the optimal number of burns and each burn's optimal TIG, and the other for computing the minimum total Δv burn solution that satisfies the trajectory constraints. Each of the two aforementioned levels uses a different optimization algorithm to solve one of

the sub-problems, giving rise to a hybrid technique. Level 2, or the outer level, uses a genetic algorithm to select the number of burns and each burn's TIG. Level 1, or the inner level, uses the burn TIGs from Level 2 in a sequential quadratic programming (SQP) algorithm to compute a minimum total Δv burn solution subject to the trajectory constraints. The total Δv from Level 1 is then used as a fitness function by the genetic algorithm in Level 2 to select the number of burns and their TIGs for the next generation. In this manner, the two levels solve their respective sub-problems separately but collaboratively until a burn solution is found that globally minimizes the Δv across the entire trajectory. Feasible solutions can also be found by simply using the SQP algorithm in Level 1 with a zero cost function.

This paper discusses the formulation of the Level 1 sub-problem and the development of a prototype software tool to solve it. The Level 2 sub-problem will be discussed in a future work. Following the Level 1 formulation and solution, several look-ahead trajectory examples for the ISS are explored. In each case, the burn targeting results using the current process are compared against a feasible solution found using Level 1 in the proposed technique. Level 1 is then used to find a minimum Δv solution given the fixed number of burns and burn TIGs. The optimal solution is compared with the previously found feasible solution to determine the Δv (and therefore propellant) savings.

The proposed technique seeks to both improve the current process for targeting ISS burns, and to add the capability to optimize ISS burns in a novel fashion. The optimal solutions found using this technique can potentially save hundreds of kilograms of propellant over the course of the ISS mission compared to feasible solutions alone. While the software tool being developed to implement this technique is specific to ISS, the concept is extensible to other long-duration, central-body orbiting missions that must perform orbit maintenance burns to meet operational trajectory constraints.